Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2025, Volume 16, Issue 3, Page 523-537

http://www.jmaterenvironsci.com

Banana (*Musa paradisiaca*) as a Green Corrosion Inhibitor for Protection of Metals and Alloys-A Review

R. T. Vashi *

Department of Chemistry, Navyug Science College, Rander Road, Surat, Gujarat, India.
**For Corresponding author: Email address: vashirajendra@yahoo.co.in*

Received *11 Feb 2025,*
Revised *17 Mar 2025,*
Accepted *19 Mar 2025*

Keywords:
- ✓ *Corrosion inhibition;*
- ✓ Banana (*Musa paradisiaca*)
- ✓ *WL;*
- ✓ *Electrochemical methods;*
- ✓ *SEM*

Citation: *Vashi R. T. (2025)* Banana (*Musa paradisiaca*) *as a Green Corrosion Inhibitor for Protection of Metals and Alloys-A Review, J. Mater. Environ. Sci., 16(3), 523-537*

Abstract: Corrosion is the deterioration of a metal by a chemical attack or reaction with its environment. Banana (*Musa paradisiaca*) can control the corrosion of various metals and alloys, such as aluminum, carbon steel, mild steel, stainless steel, iron and zinc. Various techniques like the weight loss (WL) method and electrochemical methods such as potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS), have been used to evaluate the corrosion inhibition efficiency (I.E.) of Banana. The protective film has been analyzed by Fourier-transform infrared spectroscopy (FT-IR), Gas chromatography mass spectroscopy (GC-MS), UV-visible spectroscopy (UV-Vis.) and scanning electron microscopy (SEM) methods. Adsorption of *Musa paradisiaca* on metal surfaces obeys the Langmuir, Frumkin or Temkin isotherms depending on the nature of metal and the corrosive environment. A polarization study reveals that Banana (*Musa paradisiaca*) can function as cathodic or mixed type of inhibitor.

1. Introduction

Corrosion of metal/alloy, which can be defined as the deterioration of materials due to their reaction with the environment. Corrosion of metals is of fundamental academic and industrial concern that has received considerable attention over the years. It remains a global scientific problem as it affects the metallurgical, chemical, food processing and oil industries. In Australia, Great Britain and Japan, the cost of corrosion is approximately 3 to 4 percent of the GDP (Kruger and Uhlig, 2000). Mild steel is widely use in the manufacturing of installations for the petroleum, fertilizers and other industries. In view of the viability of mild steel, its high cost of production and installation, several steps have been adopted to prolong the lifespan of the metal in industries. Aluminum has a remarkable economic and industrial importance owing to its low cost, light weight, high thermal and electrical conductivity. Zinc is one of the most important non-ferrous metals, which finds extensive use in metallic coating. Most efficient methods for protection metals against corrosion is the use of inhibitors (Kumar *et al.*, 2013, Ebenso *et al.*, 2008, Arab and Turkustani, 2006, Dubey and Singh, 2007). Corrosion inhibitors are substances which when added in small concentration to corrosive media decrease or prevent the reaction of the metal with the media (Raja *et al.*,2008). The application of the organic and inorganic inhibitors not only gives toxicity effect towards living organism, also it is quite expensive. Nowadays natural products are used as corrosion inhibitors as they are eco-friendly, cheap, easily available, non-toxic and ecologically acceptable (El-Etre *et al*., 1998; Hammouti *et al*., 2011; Elewady *et al*., 2008; Oguzie *et al*., 2006; Arrousse *et al*., 2021).

Plant extracts have the required inhibiting properties, i.e. they contain various organic compounds with heteroatoms like nitrogen, sulphur, oxygen and conjugated bonds (Vasudha *et al*., 2013, Patel *et al*., 2010, Ibrahim *et al*., 2012, Prabakaran *et al*., 2016). The plant extracts, boosted with phytochemical constituents such as amino acids, terpenoids, flavonoids, alkaloids, polyphenols, tannins, etc., along with their simple preparative methods, low cost, easy availability and renewable resources, are environmentally acceptable ones (Shahba *et al*., 2016). There are three types of inhibitors according to mechanism of electrochemical action, such as anodic, cathodic or mixed inhibitors: (i) Anodic inhibitors slow down the oxidation reaction, i.e.by blocking the anodic sites (seat of metal oxidation), which decrease the density of the metal dissolution current and shift the corrosion potential in the positive direction. (ii) Cathodic inhibitors show blocking the cathodic sites (iii) Mixed-type of inhibitors which act on both cathodic and anodic reactions.

Musa paradisiaca (Family: Musaceae) is a perennial tree like herb. It is commonly known as banana or kela in Hindi and is widely found in northern India (Bhatnagar *et al*., 2011). Almost all modern edible parthenocarpic (seedless) bananas come from two wild species – *Musa acuminata* and *Musa balbisiana*. The old scientific name *Musa sapientum* is no longer used. Banana are species of the genus Musa are native to Southeast Asia but are now grown extensively in all tropical countries like Indomalaya and Australia for their fruit, fiber, or foliage. A banana peel, called banana skin in British English, is the outer covering of a banana. It is cultivated throughout the tropical and subtropical regions which spread over 122 countries in the world (Oliveira *et al*., 2008, Ehiowemwenguan *et al*., 2014). In international trade, the banana is a fifth agricultural crop (Singh *et al*., 2016). India is the largest producer of the banana and contributes about 25.7 % to the total production in the world.

As the banana plants are normally tall and fairly sturdy, they are often mistaken for trees, but their main or upright stem is actually a pseudo stem (literally "fake stem"). When fully grown the stem attains a height of 3 to 12 m and is surmounted by a crown of large oval leaves up to 3 m long. The banana leaves are spirally arranged and may grow to 2.7 meters long and 60 cm wide and each plant has 8 to 12 leaves. The fruit is variable in size, color and firmness, but is usually elongated and curved, with soft flesh rich in starch covered with a rind which may be green, yellow, red, purple, or brown when ripe. The fruits grow in clusters hanging from the top of the plant (Ehiowemwenguan *et al*., 2014). Banana (*Musa paradisiaca*) peel is shown in Figure 1.

Figure 1. Banana (*Musa paradisiaca*) peel

***Traditional uses of* Banana (*Musa paradisiaca*)**

Banana peels are used as food for animals, an ingredient in cooking, in water purification, for manufacturing of several biochemical products. The stem juices of *Musa paradisiaca* have been reported to be used in the treatment of nervous affections like epilepsy, hysteria and in dysentery and diarrhea (Singh *et al*., 2007). Banana leaves are used as a wound dressing material and on burns (Ali *et al*., 2015). Flowers are used in treating diabetes and menstrual disorders (Bhaskar *et al*., 2011). Banana stem is used in treating urinary disorders (Poonguzhali *et al*., 1994). The root is used for anti-inflammatory property (Ibegbu *et al*., 2012). The potential use of banana fruit pulp to treat ulcers has been explored by a number of investigators (Singh *et al*., 2007, Elliot *et al*., 1976, Best, 1984). The juice of this plant works for fevers, hemorrhages, hysteria. Dysentery, digestive disorders, and diarrhea can also be cured by this plant. Anemia, blood pressure, constipation, depression can be controlled by this herb (Bhatnagar *et al*., 2011). The extract of the banana peel shows antioxidant and antibacterial properties (Hernández-Carranza *et al*., 2015, Mokbel and Hashinaga, 2005, Azarudeen *et al*., 2021). Banana peel also shows antifungal (Okorondu *et al*., 2012), anticancer activity (Azarudeen *et al*., 2021, Kamal *et al*., 2019), antimicrobial, antibiotic, and prebiotic properties (Boots *et al*., 2008, Kabir *et al*., 2020). Banana peel extract was used to reduce silver nitrate ($AgNO_3$) in the preparation of silver nanoparticles. Nowadays Banana peel extract can be used as an effective corrosion inhibitor.

2. Methodology

Corrosion inhibition of different metals and alloys in various medium by Banana (*Musa paradisiaca*) as an inhibitor was shown in **Table1**.

Table 1. Corrosion inhibition of metals and alloys in different media by Banana (*Musa paradisiaca*) as an inhibitor.

Metal / Alloy	Medium + Additive	Techniques used	Findings	I.E. max. (in %)	Reference
Aluminum and Mild Steel	H_2SO_4	WL with time,	Efficient inhibitor.	67.32 WL for Al & 62.40 WL for MS	Ayotamuno, 2023
Carbon Steel	1 M HCl & 0.5 M H_2SO_4	PDP, EIS, FT-IR, SEM, XPS.	Cathodic-type of inhibitor in HCl.	95.91 PDP in HCl & 83.33PDP in H_2SO_4	Bach *et al*., 2023
AISI 4041 Carbon Steel	0.5 and 1.5 M HCl	WL with time.	Corrosion rate decreases with increase in inhibitor concentration.	78.59 WL in 0.5 M HCl.	Komalasari *et al*., 2018
Iron	3 % HCl	WL with time, FT-IR, UV-Vis.	As the concentration of banana peel increases I.E. also increases.	97.79 WL	Tambun *et al*., 2018a
Iron	3 % NaCl	WL with time, FT-IR.	Efficient inhibitor.	67.9 WL	Tambun *et al*., 2018b
X70 Steel	1 M HCl	WL with temperature, EIS, SEM, FT-IR, MDS, QCC, AFM	Mixed-type of inhibitor. Langmuir adsorption isotherm.	90.0 WL	Guo *et al*., 2021

ASTM A53 Steel	Artificial Sea water	WL, SEM.	---	30.0 WL	Pratikno *et al.*, 2018
SS 304	1 M HCl	WL with temperature, PDP, EIS, SEM.	Mixed-type of inhibitor. Langmuir adsorption isotherm.	87.0 PDP, 98.0 EIS	Patel *et al.*, 2024
Carbon Steel	Sea water + Zn^{+2}	WL, PDP, EIS, AFM, FT-IR.	Mixed-type of inhibitor.	98.0 WL	Sangeetha *et al.*, 2012
Mild Steel	Sea water + Zn^{+2}	WL, PDP, SEM, AFM.	Mixed-type of inhibitor.	98.0 WL	Sangeetha *et al.*, 2021
Mild Steel	CO_2 corrosive environment	WL with time and temperature, FT-IR, SEM.	Efficient inhibitor.	100.0 WL	Chima *et al.*, 2024
Mild Steel	1 M HCl	WL with temperature, GM, TM, ANOVA	Efficient inhibitor.	95.56 TM	Amodu *et al.*, 2019
Mild Steel	H_2SO_4	WL, PDP, EIS, FT-IR, UV-Vis., SEM, AFM, DFT.	Efficient inhibitor.	87.0 WL	Ji *et al.*, 2021
Mild Steel	1.0, 1.5 and 2.0 M H_2SO_4	WL	Efficient inhibitor.	84.75 WL	Idemudia *et al.*, 2020
Mild Steel	2.0 M H_2SO_4	WL	---	---	Salami *et al.*, 2018
Mild Steel	1 M HCl	WL, PDP, EIS, HPLC, UV Vis., AFM, FT-IR.	Langmuir adsorption isotherm.	92.0 WL	Ji *et al.*, 2015
Mild Steel	1.0 M HCl and 0.5 M H_2SO_4	WL, PDP, EIS, UV-Vis., SEM, DFT.	Langmuir adsorption isotherm.	90.0 in both HCl, and H_2SO_4	Tiwari *et al.*, 2018
Mild Steel	0.5 M H_2SO_4	WL with temperature, PDP, EIS, SEM, AFM.	Mixed-type of inhibitor. Langmuir adsorption isotherm.	82.7 WL, 81.9 PDP, 72.6 EIS	Mayanglambam *et al.*, 2011
Mild Steel	5.0 M HCl	WL, GM, PDP, EIS, SEM.	Efficient inhibitor.	90.0 WL	Kumar *et al.*, 2020
Mild Steel (A 36 Steel)	0.5 M HCl	WL with time, SEM, Colorimetry.	Good inhibitor.	24.44 WL	Hidalgo *et al.*, 2025
Mild Steel	1 M HCl	WL, PDP, EIS.	Mixed-type of inhibitor.	94.93 WL	Gunavathy *et al.*, 2013
Mild Steel	1 M HCl	WL with time and temperature, PDP, EIS.	Mixed-type of inhibitor. Langmuir and Temkin adsorption isotherms.	96.08 WL, 99.18 PDP, 92.04 EIS	Gunavathy *et al.*, 2012
Mild Steel	1 N H_2SO_4	WL with temperature, PDP, EIS, SEM.	Mixed-type of inhibitor. Langmuir adsorption isotherm.	93.09 WL, 94.74 PDP, 91.27 EIS	Gunavathy *et al.*, 2014
Mild Steel	1 M H_2SO_4	WL with time and temperature.	Langmuir adsorption isotherm.	90.0 WL	Leizoua *et al.*, 2022
Mild Steel	1 M HCl	WL, PDP, EIS, SEM, FT-IR.	Mixed-type of inhibitor. Langmuir adsorption isotherm.	84.60 WL, 92.92 PDP, 91.0 EIS	Senthilvadivu *et al.*, 2015
Mild Steel	H_2SO_4	WL with time and temperature.	Langmuir and Frumkin adsorption isotherms.	71.05 GM, 70.05 WL	Eddy *et al.*, 2008

Mild Steel	0.5 M H_2SO_4	WL with time, FT-IR.	Langmuir adsorption isotherm.	87.07 WL	Ekeke *et al.*, 2021
Mild Steel	0.1 M HCl	WL, PDP, SEM, FT-IR,	As the concentration of banana peel increases I.E. also increases.	87.44 WL	Manikandan*et al.*, 2019
Mild Steel	0.5 M H_2SO_4	WL with time, SEM, FT-IR, EDS.	Langmuir adsorption isotherm.	94.91 WL	Verma *et al.*, 2016
Mild Steel	1 M HCl	WL with temperature, GC-MS, FT-IR.	Efficient inhibitor.	89.0 WL	Rosli *et al.*, 2019
Mild Steel	1 M HCl	WL with temperature.	Langmuir adsorption isotherm.	88.50 WL	Olasehinde *et al.*, 2012
Mild Steel	0.3 M HCl & 0.3 M H_2SO_4	WL with time.	Efficient inhibitor.	93.0 WL in HCl and 69.0 WL in H_2SO_4	Oke *et al*, 2018
Steel	2 % HCl	GC-MS.	---	36.11	Jamaluddin *et al.*, 2024
Zinc	3 % HCl	WL with time, FT-IR.	Efficient inhibitor.	90.93 WL	Tambun *et al.*, 2020

Abbrevations: ANOVA: analysis of variance, **AFM:** atomic force microscope, **DFT**: density function theory, **EDS**: energy dispersive spectroscopy, **EIS**: electrochemical impedance spectroscopy**, FT-IR**: fourier-transform infrared spectroscope, **GC-MS:** gas chromatography mass spectrometry, **GM**: gasometric method, **HPLC:** high pressure liquid chromatography, **MDS**: molecular dynamics simulation, **PDP:** potentiodynamic polarization **, SEM**: scanning electron microscopy **TM**: thermometric method**, QCC:** quantum chemical calculation, **UV-Vis**.: ultraviolet-visible spectrophotometry, **XPS**: X-ray photoelectron spectroscopy, **WL:** weight loss.

Gas chromatography mass spectrometry (GC-MS) study

Rosli et al. (Rosli *et al.*, 2019) studied of corrosion inhibition of Mild steel in 1 M HCl solution by Banana peel as corrosion inhibitor. They carried out GC-MS spectra of the Banana Peel extracts shown in **Figure 2** which indicates various levels of peaks. Identification of these compounds was confirmed by comparison of the mass spectra with the standard mass spectra obtained in the literature. Compounds that consist of particular components such as follows exhibits properties of corrosion inhibition and adsorption (Nair *et al*., 2010, Gunavathy and Murugavel 2014):

- The presence of lone pair of electrons on a hetero atom such as phosphorus, nitrogen, oxygen and sulphur
- The presence of π-bond
- The presence of triple bond such as cyano groups
- The presence of heterocyclic compound such as imidazole, pyridine ring pyrrole and so on.

Acquirable compounds of banana peel extracts have hetero atoms such as nitrogen and oxygen that fortify their adsorptive property over mild steel surface. The presence of particular groups such as C=O, COOH, OH, NH and also the existence of pi electrons in the chemical structure of banana peels enhance its inhibiting properties (Matheswaran and Ramasamy 2012, El-Maksoud 2008, Singh *et al*., 2013). Thus, from the investigation of the results, it could be concluded that the inhibition of mild steel corrosion was acknowledged due to the significant presence of these compounds in the banana peel extracts.

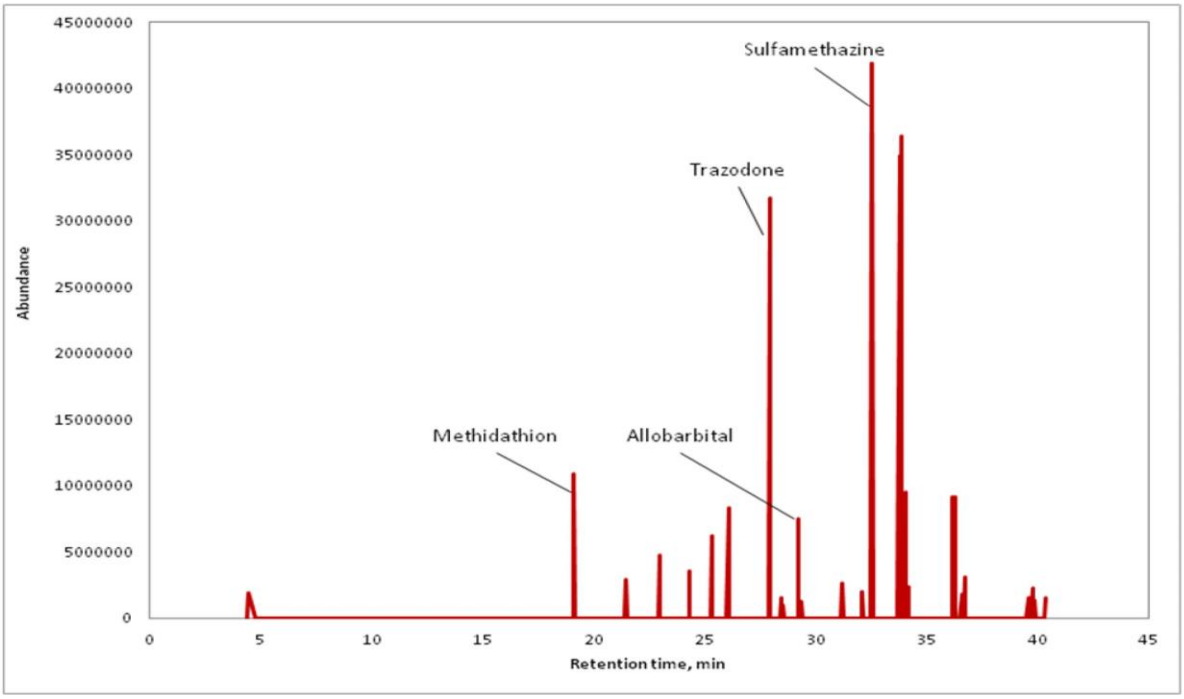

Figure 2. GC-MS Chromatogram Banana Peel Extracts (Rosli *et al.*, 2019).

Potentiodynamic polarization (PDP) Study

The polarization curves for mild steel in 1 M HCl in the absence and presence of different concentrations Musa paradisiaca are given in **Figure 3** (Senthilvadivu *et al.*,2015). The potentiodynamic polarisation measurement allows for the study of anticorrosion behaviour via anodic and cathodic polarisations. Tafel plots as shown in **Figure 3.**

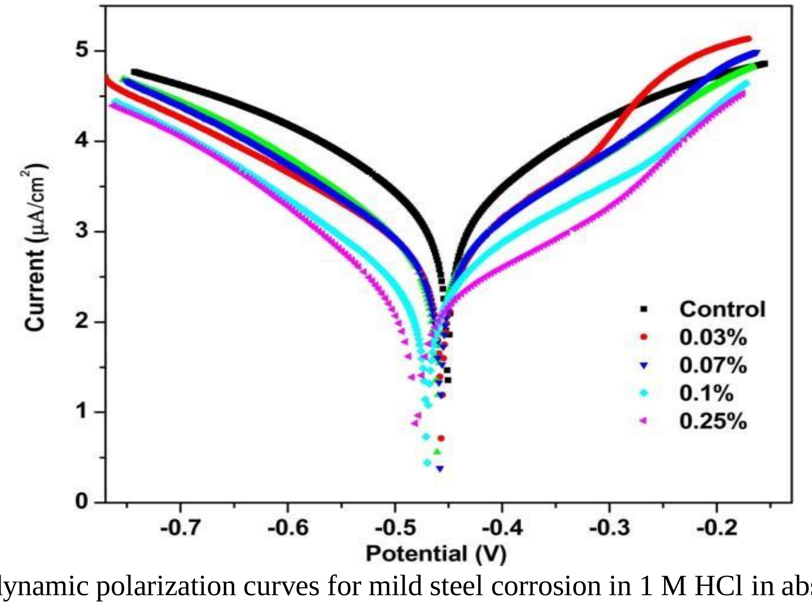

Figure 3. Potentiodynamic polarization curves for mild steel corrosion in 1 M HCl in absence and presence of different concentrations Musa paradisiaca (Senthilvadivu *et al.*, 2015).

E_{corr} refers to the corrosion potential, I_{corr} refers to the corrosion current density, βa and βc refer to the anodic and cathodic Tafel slopes, respectively, of the polarisation curves. The flow of electrons is inhibited with increase in concentration of inhibitor banana peel, which is due to the adsorption of inhibitor molecules on the metal surface. An Inhibitor is classified as cathodic or anodic with the E_{Corr}

value displacement from the control is greater than 85 mV. If the value is less than 85 mV, then the inhibitor is considered to be mixed type inhibitor. Our inhibitor has $E_{Corr.}$ value displacement less than 85 mV. The significance of βa and βc Value, we can see that βa is greater than βc this indicates that extract has high cathodic current density than the anodic part. The result implies that the inhibitor used as mixed type of inhibitor and predominantly inhibiting cathodic reaction (Senthilvadivu *et al.*, 2015).

***Electrochemical impedance spectroscopy (EIS)* study**

Senthilvadivu et al. (Senthilvadivu *et al.*, 2015) studied EIS diagrams for Mild steel in 1 M HCl and Nyquist plots were shown in **Figure 4**.

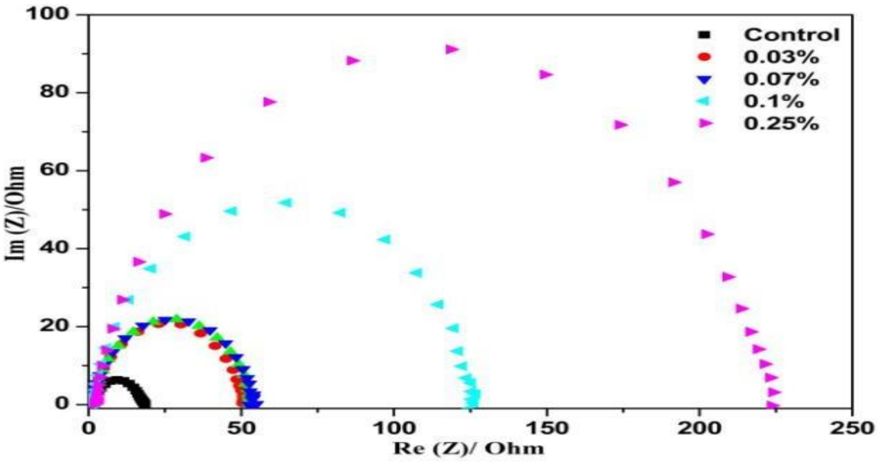

Figure 4. Nyquist plots (Senthilvadivu *et al.*, 2015).

It is observed that with increase in concentration of inhibitor, the diameter of loop is increasing. The diameter of the loop indicates the resistance towards the flow of electrons. The increase in diameter of loop with concentration implies increase in resistance (R_{ct}) towards flow of electrons. This is due to the formation of the inhibitor as a protective film on the metal surface, which acts as a potential barrier against corrosive environment. It was observed that the inhibition efficiency (I.E. %) shows increasing trend with concentration of inhibitor and the inhibition efficiency of 91% was found to be at concentration (0.25%). These results showed that the banana peel extract acts as an effective corrosion inhibitor (Senthilvadivu *et al.*, 2015).

Fourier transform infrared spectroscopy (FT-IR) study

FTIR analysis is an analysis using infrared radiation absorption. Each functional group in a material absorbs a different spectrum so that the chemical characteristics of the material as a whole can be described. FTIR test results in the form of graphs, which consists of several absorption peaks that identify the compounds contained in the banana peel. Tabun et al. (Tabun *et al.*, 2018a) studied the inhibitive effect of Banana peels on the corrosion of Iron in 3% NaCl. In this study, banana peel extract was characterized by using FT-IR spectra was shown in **Figure 5. Figure 5** shows that the banana peel contains a phenol (O-H) group which is marked at the peak of absorption 3398.57 cm^{-1} where the hydroxyl group wave number area is 3705-3125 cm^{-1}. Peak 2927.94 cm^{-1} indicates that Awak banana peel contains alkane (C-H) compounds which according to theory at wave length 2863-2961 cm^{-1}, while peak 1631.78 cm^{-1} indicates the amide compound (C=O) which according to the theory at wave length 1300-1655 cm^{-1}, peak 3132, 3544 cm^{-1} for gallic acid and peak 3232, 3441 cm^{-1} indicates tannic acid as specific commercial form of tannin (Sun Da-Wen, 2009). The FTIR test result indicates that the banana peel contains tannin compounds. The results of the FTIR analysis in this study are similar to the results of the analysis conducted by Zhao et al. (Zhao *et al.*, 2018).

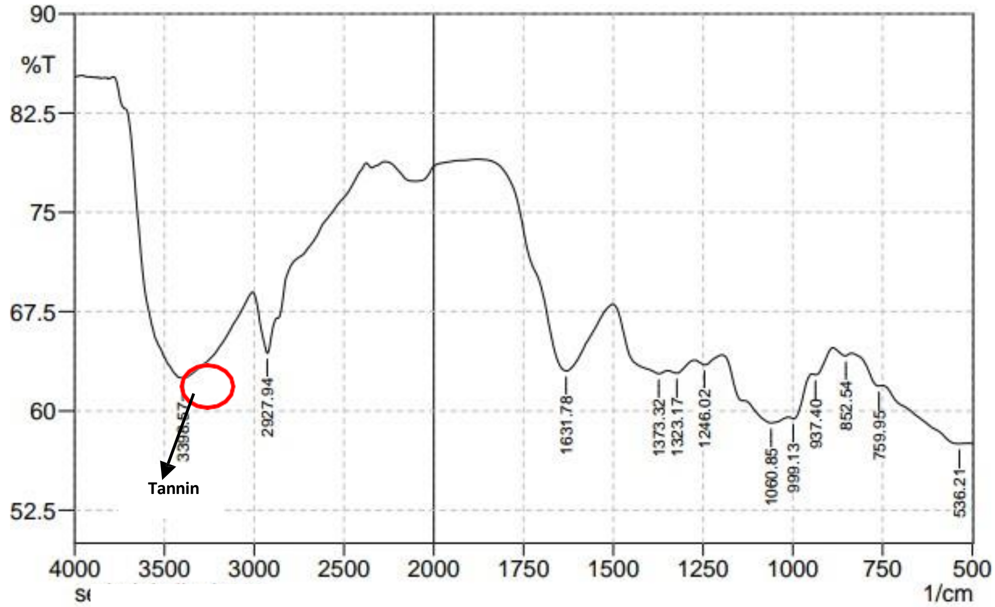

Figure 5. FTIR spectrum of banana peel (Tabun *et al*., 2018a)

Atomic force microscopy (AFM) studies

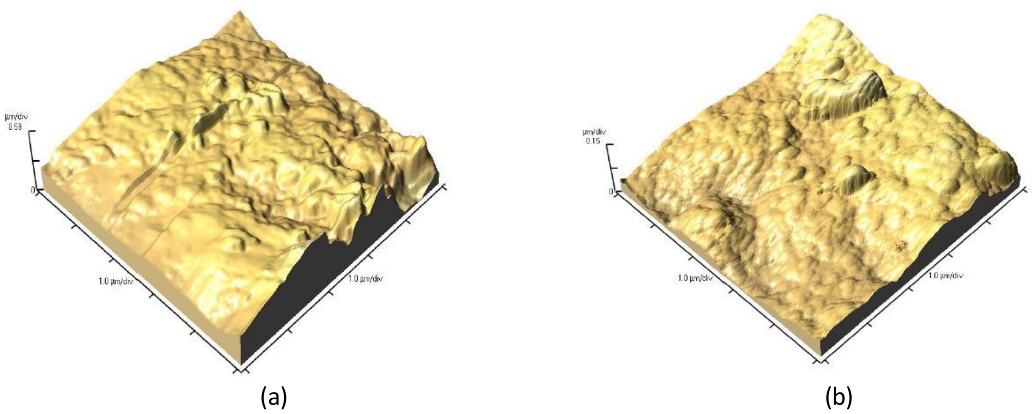

Figure 6. AFM images of mild steel in 0.5 M H_2SO_4 in (a) absence and (b) presence of 3 g of *Musa paradisiaca* extract (Mayanglambam *et al.*, 2011).

Mayanglambam et al. (Mayanglambam *et al.*, 2011) studied AFM images of mild steel exposed for 5 hours in 0.5 M H_2SO_4 solutions in absence and presence of 1 gram of extract are shown in **Figure 6** (a)-(b). The roughness of mild steel coupons in 0.5 M H_2SO_4 solutions in absence and presence of the extract are 152.9 nm and 56.99 nm, respectively (Sheng *et al*., 2007). This indicates that the addition of the extract reduced the surface roughness. This confirms that the corrosion inhibition on mild steel occurs through adsorption of the extract on it (Mayanglambam *et al.*, 2011).

Scanning Electron Microscopy (SEM) Study

Verma and Khan (Verma and Khan, 2016) studied the SEM images of mild steel surface before and after exposing to 0.5 M H_2SO_4 solution in absence and presence of banana leaves for 24 h are shown in **Figure 7**.

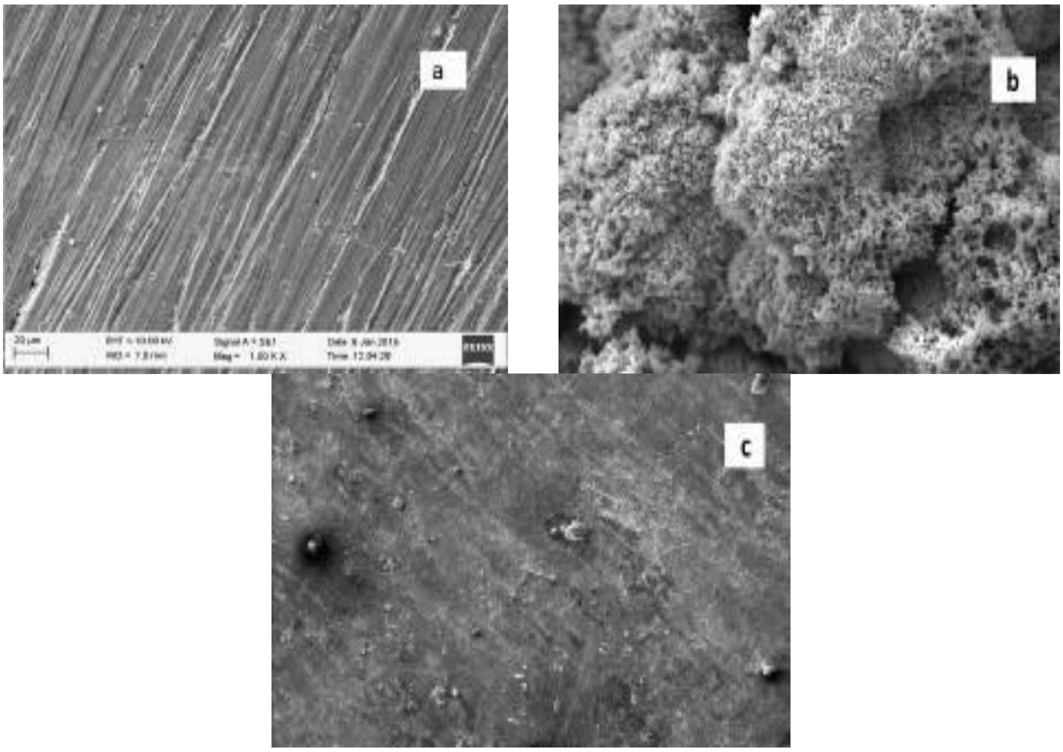

Figure 7. SEM images of mild steel surfaces (**a)** polished mild steel (**b)** mild steel after immersion in 0.5 M H_2SO_4, (**c**) mild steel after immersion into inhibitor solution (Verma and Khan, 2016).

Figure 7b and **Figure 7c** shows the SEM images of mild steel surface that was immersed in 0.5 M H_2SO_4 solution in the absence and presence of inhibitor for 24 h, respectively. The SEM image of mild steel surface in **Figure 7a** shows the plane surface. Whereas from **Figure 7b** it is obviously seen that the metal surface was severely corroded due to presence of corrosive solution. However, the appearance of mild steel surface is different after the addition of the inhibitor solution shown in **Figure 7c**. The uniform distribution of inhibitor on the high carbon steel surface prevents the further corrosion. SEM analysis results show that inhibitor molecules form protective layer over the metal surface and prevent from the further corrosion (Verma and Khan, 2016).

Energy dispersive spectroscopy (EDS) study

EDX is a technique used to identify and quantify the elemental composition of materials by analyzing the X-rays emitted when a sample is bombarded with a focused electron beam. Verma and Khan (Verma and Khan, 2016) studied the EDS spectra of surface of the mild steel specimens in 0.5 M H_2SO_4 solution in absence and presence of *banana leaves* extract are shown in **Figure 8**. Based on the corresponding EDS spectrum of **Figure 8a**, it can be concluded that the mild steel surface corroded in aggressive media has areas with clearly high oxygen concentration compared to the surface in the presence of *banana leaves* extract (Verma and Khan, 2016).

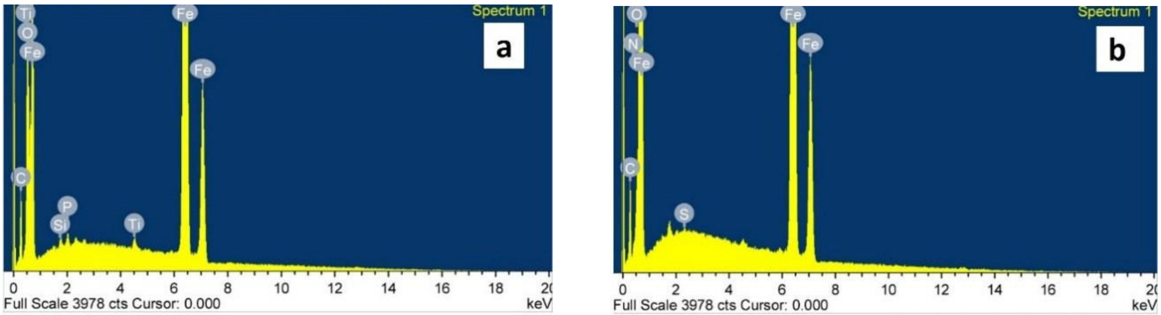

Figure 8. EDS spectra mild steel surfaces (**a)** mild steel after immersion in 0.5 M H_2SO_4 and (**b)** mild steel after immersion into inhibitor solution (Verma and Khan, 2016).

***Phytochemical constituents of Banana (Musa paradisiaca*)**

Phytochemical analysis of *Musa acuminata* bract showed the presence of alkaloids, flavonoids, saponins, tannins, terpenoids, coumarins, glycosides, total phenols and steroids (Gunavathy and Murugavel 2014). Banana peel has a high source of total dietary fiber (43-49%), crude protein (6-9%), crude fat (3.8-11%), starch (3%), and polyunsaturated fatty acids (PUFA) especially linoleic acid α linoleic acid. It includes essential amino acids such as leucine, valine, phenylalanine, threonine, and micronutrients such as calcium, magnesium, potassium, sodium and phosphorous. The rich micronutrients, iron and zinc are present more in the peel than the pulp. It is also a rich source of pectin (10-21%), lignin (6-12%), cellulose (7.6 9.6%), and hemicellulose (6.4-9.4%) (Mohapatra *et al*., 2010). GC-MS showed that the peels were rich with lipids, fatty acids, and terpenoids. The fatty acids stearic, palmitic, oleic and linoleic acids and their methyl esters as well as cyclododecane, dibutyl phthalate, b-sitosterol, sesamin and epi-sesamin were among the identified components.

Mechanism of corrosion inhibition by Banana (*Musa paradisiaca*)

The mechanism of inhibition can be understood by knowing the mode of interaction of the inhibitor molecules with mild steel surface. Inhibitors function by adsorption and/or hydrogen bonding to the metal. Adsorption process can be governed by various parameters. This depends on the chemical composition and structure of the inhibitor, the nature of the metal surface, and the properties of the medium. Structural and electronic parameters like functional group, steric and electronic effects may also be responsible for the inhibition efficiency of any inhibitor, that is, the adsorption mechanism. The compounds have to block the active corrosion sites on the metal surface and hence the adsorption occurs by the bonding of the free electrons of inhibitor with the metal. The bract extract may constitute organic compounds containing (i) lone pair of electrons present on a hetero-atom (e.g., N, S, P, O) (ii) pi-bond (iii) triple bonds (e.g., Cyano groups) and (iv) heterocyclic compounds such as pyridine ring pyrrole, imidazole etc. Phytochemical analysis of *Musa acuminata* bract showed the presence of alkaloids, flavonoids, saponins, tannins, terpenoids, coumarins, glycosides, total phenols and steroids. The inhibiting influence of these molecules may be attributed to their adsorption through the NH, C=O, OH, COOH etc. groups and also may be due to the presence of pi-electrons in the rings (Gunavathy and Murugavel *et al*., 2014). These organic molecules get physisorbed on the metal surface forming a protective film and hence the anti-corrosive behaviour (Rekha *et al*.,2010). The plant nutrients sitosterol, stigmasterol, campesterol, cycloeucalenol, cycloartanol, and 24-methylene cycloartanol have either nitrogen or oxygen or both and pair of electrons in nitrogen and oxygen can facilitate the adsorption of the nutrients of the extract on metals. Interaction between the π electrons of oxygen and the vacant d orbital of the metal surface may also be another possibility for adsorption and for inhibition (Gunavathy and Murugavel 2012, Poongothai *et al.*, 2010). Banana peel includes essential amino acids (Mohapatra *et al*., 2010) such as leucine, valine, phenylalanine and threonine and their chemical structures are shown in **Figure 9.** Amino acids were widely studied as good to excellent inhibitors for iron and its alloys in various aggressive media (El Ibrahimi *et al*., 2020; Barouni *et al*., 2014; Aouniti *et al*., 2013).

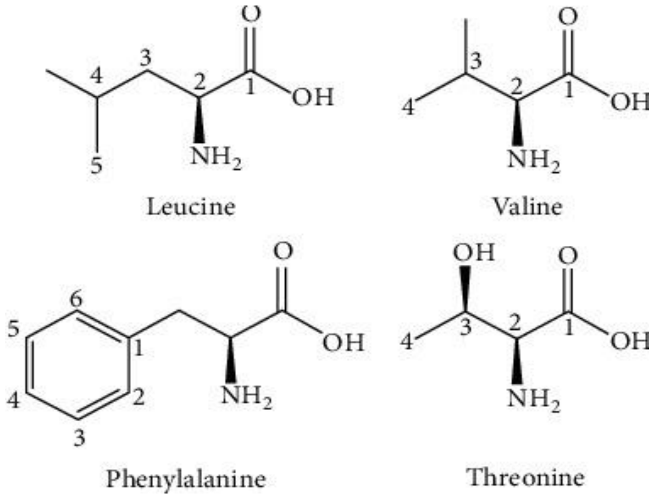

Figure 9. The chemical structures of some amino acids.

Inspection of the chemical structures of these phytochemical constituents reveal that these compounds are easily hydrolysable and the compounds can be adsorbed on the metal surface via the lone pair of electrons present on their oxygen atoms (i.e. they contain multifunctional group) which make a barrier for charge and mass transfer leading to decrease the interaction of the metal with the corrosive environment. As a result, the corrosion rate of the metal was decreased. The formation of film layer essentially blocks the discharge of H^+ and dissolution of the metal ions. Due to electrostatic interaction, the protonated constituent molecules are adsorbed (physisorption) and high inhibition is expected (Olasehinde *et al.*, 2012). The various naturally components adsorb competitively on the metal surface to ensure the corrosion attack via the synergistic intermolecular effect (Eziuka *et al.*, 2023; Lrhoul *et al.*, 2023; Lazrak *et al.*, 2021)

Conclusion

In this review, various research works on the corrosion inhibition of different metals and alloys in different acidic, neutral and seawater media by Banana (*Musa paradisiaca*) peel as green inhibitor were presented. Langmuir, Frumkin and Temkin adsorption isotherms were observed. Banana peel extract behaved as a cathodic or mixed-type of inhibitor. The maximum inhibition efficiency for Banana (*Musa paradisiaca*) peel was found to be 100.0 % (WL data). The results obtained from weight loss data were in good agreement with the results obtained from the PDP and EIS methods. Various techniques such as SEM, FT-IR, GC-MS, DFT, UV-Vis. etc. were used to study the corrosion mechanism.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

Ali W. G. and Bayumi H. A. (2015) The Effectiveness of Using Banana Leaf Dressing in Management of Partial Thickness Burns' Wound. *Int. J. Nurs. Didactics*, 5(4), 22-27.

Amodu O. S., Odunlami M. O., Akintola J. T., Ntwampe S. K. *et al.* (2019) Exploring *Musa paradisiaca* Peel Extract as a Green Corrosion Inhibitor for Mild Steel Using Factorial Design Method, Corrosion Inhibitors. https://doi.org/10.5772/intechopen.82617

Aouniti A., Khaled K.F., Hammouti B. (2013), Correlation Between Inhibition Efficiency and Chemical Structure of Some Amino Acids on the Corrosion of Armco Iron in Molar HCl, *Int. J. Electrochem. Sci.*, 8(4), 5925-5943, https://doi.org/10.1016/S1452-3981(23)14731-6

Arab S. T. and Turkustani A. M. (2006) Inhibition of the corrosion of steel in phosphoric acid by phenacyl dimethyl sulfonium bromide and some of its para-substituted derivatives, *Port. Electrochim. Acta*, 24, 53-69.

Arrousse N., Salim R., Abdellaoui A., ElHajjaji F., *et al.* (2021), Synthesis, characterization, and evaluation of xanthene derivative as highly effective, nontoxic corrosion inhibitor for mild steel immersed in 1 M HCl solution, *Journal of the Taiwan Institute of Chemical Engineers*, 120, 344-359, https://doi.org/10.1016/j.jtice.2021.03.026

Ayotamuno C. (2023) Inhibiting Effect of Banana Peel Extract (BPE) On the Corrosion of Aluminium and Mild Steel in a Sulphuric Acidic Environment, *Iconic Res. and Eng. J.*, 6(9), 54-60.

Azarudeen A. M. and Nithya R. (2021) Pharmaceutical Aspects of Banana peel: A Review, *J. Pharm. Sci. & Res*.,13(2), 112-117.

Bach L. X., Dao T. B. N., Duong-Ngo K. L., Tran T. N. *et al.* (2023) Inhibitive behaviours of unripe banana peel extract for mitigating electrochemical corrosion of carbon steel in aggressively acidic solutions, *J. Taibah Uni. for Sci*., 17(1), 2247633, https://doi.org/10.1080/16583655.2023.2247633

Barouni K., Kassale A., Albourine A., *et al.* (2014), Aminoacids as corrosion inhibitors for copper in nitric acid medium: Experimental and theoretical study, *J. Mater. Environ. Sci.* 5 (2), 456-463

Best R. (1984) The antiulcerogenic activity of the unripe plantain banana, *Brit. J. Pharmac*., 82(1), 107-116. https://doi.org/10.1111/j.1476-5381.1984.tb16447.x

Bhatnagar S., Garg V. K., Sharma P. K. and Jain S. (2011) Antiulcer activity of aqueous extract of *Musa paradisiaca*, *Der Pharmacia Sinica*, 2 (4), 40-43.

Bhaskar J. J., Shobha M. S., Sambaiah K. and Salimath P.V. (2011) Beneficial effects of banana (Musa sp. var. elakki bale) flower and pseudostem on hyperglycemia and advanced glycation end-products (AGEs) in streptozotocin-induced diabetic rats, *J. Physiol. Biochem*., 67(3), 415-25. https://doi.org/10.1007/s13105-011-0091-5

Boots A. W., Haenen G. R. and Bast A. (2008) Health effects of quercetin: From antioxidant to nutraceutical, *Eur. J. Pharmacol.*, 585 (2-3), 325–337. https://doi.org/10.1016/j.ejphar.2008.03.008

Chima M. O., Popoola L. T., Archibong F. N. , Nwokeocha T. O. et al. (2024) A novel application of CO_2 corrosion inhibitory potentials of banana peel extract on mild steel: Experimental studies, *South Afri. J. of Chem. Eng.*, 47(1), 246-253. https://doi.org/10.1016/j.sajce.2023.11.011

Dubey A. K. and Singh G. (2007), Corrosion inhibition of mild steel using Brij-30, *Port. Electrochim. Acta*, 25(2), 205-219.

Ebenso E. E., Eddy N. O. and Odiongenyi A. O. (2008) Corrosion inhibitive properties and adsorption behaviour of ethanol extract of Piper guinensis as a green corrosion inhibitor for mild steel in H_2SO_4, *Afri. J. Pure & Appl. Chem.*,4(11), 107-115.

Eddy N. O. and Ebenso E. E. (2008) Adsorption and inhibitive properties of ethanol extracts of Musa sapientum peels as a green corrosion inhibitor for mild steel in H_2SO_4, *Afr. J. Pure Appl. Chem.*, 2(6), 046-054.

Ehiowemwenguan G., Emoghene A. O. and Inetianbor J. E. (2014) Antibacterial and phytochemical analysis of Banana fruit peel. IOSR *J. Pharm*., 4(8),18-25.

Ekeke I. C., Umosah S. O. and Nkwocha A. C. (2021) Musa Paradisiaca (Plantain) Stem Sap Extract as a Potential Corrosion Inhibitor on Mild Steel in Acid Medium, *Int. J. Innovative Sci. and Res. Tech*., 6(12), 659-664.

El-Etre A. Y. (1998) Natural honey as corrosion inhibitor for metals and alloys. I. Copper in neutral aqueous solution, *Corros. Sci*., 40(11), 1845-1850. https://doi.org/10.1016/S0010-938X(98)00082-1

Elewady G. Y., El-Said I. A. and Fouda A. S. (2008) Effect of Anions on the Corrosion Inhibition of Aluminum in HCl using Ethyl Trimethyl Ammonium Bromide as Cationic Inhibitor, *Int. J. Electrochem. Sci.*, 3(5), 644-655. https://doi.org/10.1016/S1452-3981(23)15550-7

El Ibrahimi B., Jmiai A., Bazzi L., El Issami S. (2020), Amino acids and their derivatives as corrosion inhibitors for metals and alloys, *Arabian Journal of Chemistry*, 13, Issue 1, 740-771, ISSN 1878-5352, https://doi.org/10.1016/j.arabjc.2017.07.013

Elliot R. C. and Heward E. J. F. (1976) The influence of a banana supplemented diet on gastric ulcers in mice, *Pharm. Res. Commun*., 8(2), 167-171. https://doi.org/10.1016/0031-6989(76)90006-0

El-Maksoud S. A. (2008) The effect of organic compounds on the electrochemical behaviour of steel in acidic media. A review. *Int. J. Electrochem. Sci*., 3(5), 528-555. https://doi.org/10.1016/S1452-3981(23)15542-8

Eziuka J. E., Onyeachu I. B., Njoku D. I., Nwanonenyi S. C., Chidiebere M. A., Oguzie E. E. (2023) Elucidating the inhibition behavior of Pterocarpus santalinoides leaves extract on mild steel corrosion in H2SO4 solution–GC-MS, FTIR, SEM, Experimental and computational approach, *Mor. J. Chem.*, 11(3), 579-593

Gunavathy N. and Murugavel S. C. (2012) Corrosion Inhibition Studies of Mild Steel in Acid Medium Using Musa Acuminata Fruit Peel Extract, *E-J. Chem*., 9(1), 487-495. https://doi.org/10.1155/2012/952402

Gunavathy N. and Murugavel S. C. (2013) Corrosion inhibition study of bract extract of Musa acuminata inflorescence on mild steel in hydrochloric acid medium, *IOSR J. appl. Chem*., 5(2), 29-35.

Gunavathy N., Murugavel S. C. (2014) Musa acuminata Bract Extract as Corrosion Inhibitor for Mild Steel, *Chem. Sci. Rev. Lett*., 3(11S), 70-79.

Guo L., Tan B., Li W., Li Q., Zheng X., Obot I. B. (2021) Banana leaves water extracts as inhibitor for X70 steel corrosion in HCl medium, *J. Mol. Liq.*, 327, 114828. https://doi.org/10.1016/j.molliq.2020.114828.

Hammouti B., Zarrouk A., Al-Deyab S.S., Warad I. (2011) Temperature Effect, Activation Energies and Thermodynamics of Adsorption of ethyl 2-(4-(2-ethoxy-2-oxoethyl)-2-p-Tolylquinoxalin-1 (4H)-yl) Acetate on Cu in HNO_3, *Oriental Journal of Chemistry*, 27 (1), 23-31

Hernández-Carranza P., Ávila-Sosa R., Guerrero-Beltrán J., Navarro-Cruz A. *et al.* (2015) Optimization of antioxidant compounds extraction from fruit by-products: Apple pomace, orange and banana peel, *J. Food Process. Preserv.*,40 (1), 103–115. https://doi.org/10.1111/jfpp.12588

Hidalgo D., Montero C., Luna D., Pazmiño V. et al. (2025) Evaluation of Banana-Derived Inhibitor for Corrosion Control in Mild Steel, *Civil Eng. and Arch.*, 13(1), 664-677. https://doi.org/10.13189/cea.2025.130142

Ibrahim T., Alayan H. and Al Mowaqet Y. (2012). The effect of Thyme leaves extracts on corrosion of mild steel in HCl, *Prog. in Org. Coat.*, 75(4), 456-462.

Idemudia O. S. and Maliki M. (2020) Studies on the Inhibitive Action of Musa Paradisiaca Stem Extrude on Corrosion of Mild Steel in an Acidic Medium, *Int. J. Sci. Technol*., 8(4), 9-15. https://doi.org/10.24940/theijst/2020/v8/i4/ST2004-011

Ibegbu A. O., Okonji U. J., Hamman W. O., Umana U. E. et al. (2012) Anti-inflammatory effects of the aqueous Extracts of plantain roots (Musa Species), *Br. J. Pharmacol. Toxicol*., 3(2), 70-75.

Jamaluddin J. B., Paramitha T., Salsabila I. N., Luviana A. et al. (2024) Characterization of Banana Peel Corrosion Inhibitor by Vacuum Microwave Assisted Extraction (VMAE) Method in 2% HCl Environment. *Int. J. Applied Tech. Res.*, 5(1), 1-6. https://ijatr.polban.ac.id/ijatr/article/view/144

Ji G., Singh S. K. and Prakash R. (2021) Influence of the maturity of Musa paradisica peels on mild steel corrosion in sulfuric acid. *J. Adhes. Sci. Technol.*, 36(1), 1418-1438. https://doi.org/10.1080/01694243.2021.1970372

Ji G., Anjum S., Sundaram S., Prakash R. (2015) Musa paradisica peel extract as green corrosion inhibitor for mild steel in HCl solution, *Corros. Sci.*, 90, 107–117. https://doi.org/110.1016/j.corsci.2014.10.002.

Kabir M. R., Hasan M. M., Islam M. R., Haque A. R. et al. (2020) Formulation of yogurt with banana peel extracts to enhance storability and bioactive properties, *J. Food Process. Preserv.*, 45, e15191, 1-10. https://doi.org/10.1111/jfpp.15191

Kamal A. M., Taha M. S. and Mousa A. M. (2019) The Radioprotective and Anticancer Effects of Banana Peels Extract on Male Mice, *J. Food Nutr. Res*., 7(12), 827-835. https://doi.org/10.12691/jfnr-7-12-3

Komalasari, Utami S. P., Fermi M. I., Aziz Y., Irianti R. S. (2018) Corrosion control of carbon steel using inhibitor of banana peel extract in acid diluted solutions, IOP Conference Series: *Mater. Sci. and Eng*., 345,1-8, 012030. https://doi.org/10.1088/1757-899X/345/1/012030

Kruger J. and Uhlig W. (2000) Corrosion Handbook, 2nd edition, Wiley, (pp. 165 – 70.)

Kumar, H. and Yadav V. (2020) Musa acuminata (Green corrosion inhibitor) as anti-pit and anti-cracking agent for mild steel in 5M hydrochloric acid solution, *Chemical Data Collections*, 29, 1–10. https://doi.org/10.1016/j.cdc.2020.100500

Kumar S., Sharma D., Yadav P. et al. (2013) Experimental and quantum chemical studies on corrosion inhibition effect of synthesized organic compounds on N80 steel in hydrochloric acid, *Ind. Eng. Chem. Res.* 52(39),14019-14029. https://doi.org/10.1021/ie4013 08v

Lazrak J., Assiri El H., Arrousse N., El-Hajjaji F., *et al*, Origanum compactum essential oil as a green inhibitor for mild steel in 1 M hydrochloric acid solution: Experimental and Monte Carlo simulation studies, *Materials Today: Proceedings*, 45(8) (2021) 7486-7493; https://doi.org/10.1016/j.matpr.2021.02.233

Leizoua K. E. and Ashraf M. A. (2022) Evaluation of corrosion inhibitive properties of native banana (Musa acuminate colla) on mild steel in 1 M sulphuric acid (H_2SO_4), *Acta Mech. Malaysia*, 5(1), 24-30. http://doi.org/10.26480/amm.01.2022.24.30

Loukili H., Azzaoui K., Bouyanzer A., Kertit S. et al. (2022) Corrosion inhibition using green inhibitors: An overview, *Maghrebian J. of Pure & Appl. Sci*., 8(2), 82-93. https://doi.org/10.48383/IMIST.PRSM/mjpas-v8i1.29392

Lrhoul H., Sekkal H., Hammouti B. (2023) Natural Plants as Corrosion Inhibitors: Thermodynamic's restrictions, *Mor. J. Chem.*, 14(3), 689-698, https://doi.org/10.48317/IMIST.PRSM/morjchem-v11i3.40144

Manikandan C. B., Balamurugan S., Balamurugan P. and Beneston S. L. (2019) Corrosion inhibition of mild steel by using banana peel extract, *Int. J. Innovative Tech. and Exploring Eng.*, 8(6), 1372–1375. https://api.semanticscholar.org/CorpusID:212588459.

Matheswaran P. and Ramasamy A. K. (2012) Corrosion inhibition of mild steel in citric acid by aqueous extract of Piper Nigrum L., *E-J. of Chem*., 9(1), 75-78. https://doi.org/10.1155/2012/803098

Mayanglambam R. S., Sharma V., Singh G. (2011) Musa Paradisiaca extract as a green inhibitor for corrosion of mild steel in 0.5 M sulphuric Acid Solution, *Port. Electrochim. Acta*, 29(6), 405-417 https://doi.org/10.4152/pea.201106405

Mohapatra D., Mishra S., Sutar N. (2010) Banana and its by-product utilisation: an overview. *J. Sci. Ind. Res*., 69, 323-9.

Mokbel M. S. and Hashinaga F. (2005) Antibacterial and antioxidant activities of Banana fruits peel, *American J. Biochem. Biotech.*, 1(3), 125-131. https://doi.org/10.3844/ajbbsp.2005.125.131

Nair R. N., Sharma S., Sharma I. K. and Verma P. S. et al. (2010) Inhibitory efficacy of Piper Nigrum Linn. extract on corrosion of AA1100 in HCl, *Rasyan J. of Chem.*, 3(4), 783-795.

Oke O. O., Nenuwa O. B., Boluwade E. A. (2018) Inhibiting effects of banana peel extract (BPE) on the corrosion of mild steel in acidic media, *Int. J. of Eng. Applied Sci. and Tech.*, 3(3), 6-10.

Okorondu S. I., Akujobi C. O., Nwachukwu I. N. (2012) Antifungal properties of Musa paradisiaca (Plantain) peel and stalk extracts, *Int. J. Biol. Chem. Sci.*, 6 (4), 1527-1534. https://doi.org/10.4314/ijbcs.v6i4.12

Oliveira L., Freire C. S., Silvestre A. J., Cordeiro N. (2008) Lipophilic extracts from banana fruit residues: a source of valuable phytosterols, *J. Agric. Food Chem.*, 56(20), 9520-4. https://doi.org/10.1021/jf801709t

Olasehinde E. F., Adesina A. S., Fehintola E. O., Badmus B. M. et al. (2012) Corrosion Inhibition Behaviour for Mild Steel by Extracts of Musa sapientum Peels in HCl Solution: Kinetics and Thermodynamics Study, *IOSR J. Appl. Chem*., 2(6), 15-23. https://doi.org/10.9790/5736-0261523

Oguzie E. E. (2006) Studies on the inhibitive effect of *Occimum viridis* extract on the acid corrosion of mild steel, *Mater. Chem. Phys.*, 99 (2-3), 441-446. https://doi.org/10.1016/j.matchemphys.2005.11.018

Patel N., Rawat A., Jauhari S. and Mehta G. (2010) Inhibitive action of Bridelia retusa leaves extract on corrosion of mild steel in acidic media, *Eur. J. Chem.*, 1(2),129-133. https://doi.org/10.5155/eurjchem.1.2.129-133.52

Patel J. and Patel D. D. (2024) Corrosion Inhibition by Musa paradisiaca Peel Extract for SS 304 in 1 M Hydrochloric Acid Solution, *Indian J. Sci. and Tech*., 17(18), 1854-1859. https://doi.org/10.17485/IJST/v17i18.570

Poongothai N., Ramachanderen T., Natesan M. and Murugavel S. C. (2010) Essential Oils as VCIs for Mild Steel in Various Environments, NACE International, *Mater. Perform*., 49(4), 50-55.

Poonguzhali P. K. and Chegu H. (1994) The influence of banana stems extract on urinary risk factors for stones in normal and hyperoxaluric rats, *Br. J. Urol*., 74, 23-5. https://doi.org/10.1111/j.1464-410X.1994.tb16539.x

Prabakaran M., Kim S. H., Hemapriya V. et al. (2016) Rhus verniciflua as a green corrosion inhibitor for mild steel in 1 M H_2SO_4, *RSC Adv*., 6(62), 57144-57153. https://doi.org/10.1039/C6RA09637A

Pratikno H., Titah H. S., and Shandy Y. K. (2018) Bio-Inhibitor on Corrosion Rate of ASTM A53 Steel in Marine Environment, MATEC Web of Conferences, 177, 01019. https://doi.org/10.1051/matecconf/201817701019

Raja P. B. and Sethuraman M. G. (2008) Natural products as corrosion inhibitor for metals in corrosive media—a review, *Mater. Lett*., 62(1), 113–116. https://doi.org/10.1016/j.matlet.2007.04.079

Rekha N. N., Sharma S., Sharma I. K., Verma P. S. et al. (2010) Inhibitor efficacy of *Piper Nigrum Linn*. extract on corrosion of AA1100 in HCl, *Rasayan J. Chem.*, 3, 783-795.

Rosli N. R., Yusuf, S. M., Sauki A. & Razali W. M. R. W. (2019) Musa Sapientum (Banana) Peels as Green Corrosion Inhibitor for Mild Steel, *Key Eng. Mater.*, 797, 230–239. https://doi.org/10.4028/www.scientific.net/kem. 797.230

Salami L. and Umar M. (2018) Kinetics study of corrosion of mild steel in sulphuric acid using musa sapientum peels extract as inhibitor, *J. Nigerian Soc. Chem. Eng*., 33(2), 105-109.

Sangeetha M., Rajendran S., Sathiyabama J. and Prabhakar P. (2012) Eco friendly extract of Banana peel as corrosion inhibitor for carbon steel in sea water, *J. Nat. Prod. Plant Resour*., 2 (5), 601-610.

Sangeetha M., Madhan D., Rajendran S. (2021) Corrosion Inhibition of Hydrophobic Nano Film of Eco-Friendly Banana peel Extract on Mild Steel in Seawater, *Der Pharma Chemica*, 13(11), 63-70.

Senthilvadivu B., Aswini V. and Kumar K. S. (2015) Anti-Corrosive Behavior of Ethanolic Extract of Banana Peel against Acidic Media and their Thermodynamic Studies, *Int. J. Sci. and Res.*, 6(7), 1762–1768.

Sheng X., Ting Y. P. and Pehkaonen S. O. (2007) Evaluation of an Organic Corrosion Inhibitor on Abiotic Corrosion and Microbiologically Influenced Corrosion of Mild Steel, *Ind. Eng. Chem. Res.*,46(22), 7117-7125. https://doi.org/10.1021/ie070669f

Singh A., Singh V. K. and Quraishi M. A. (2013) Inhibition of mild steel corrosion in HCl solution using Pipali (Piper longum) fruit extract, *Arabian J. for Sci. and Eng.*, 38(1), 85-97. https://doi.org/10.1007/s13369-012-0409-9

Singh B., Singh J. P., Kaur A., Singh N. (2016) Bioactive compounds in banana and their associated health benefits–A review, *Food Chem*., 206, 1-11. https://doi.org/10.1016/j.foodchem.2016.03.033

Singh S. K., Kesai A. N., Rai P. K., Watal G. (2007) Assessment of glycemic potential of musa paradisiaca stem juice, *Ind. J. Clinical Biochem.*, 22(2), 48-52. https://doi.org/10.1007/BF02913313

Sun Da-Wen (2009) Infrared Spectroscopy for Food Quality Analysis and Control Academic press, New York, USA.

Tambun R., Christamore E., Pakpahan Y. F., Haryanto B. (2018a) Banana Peel Utilization as the Green Corrosion Inhibitor of Iron in NaCl Medium, IOP Conference Series: *Mater. Sci. and Eng.*, 420 012059, 420(1). https://doi.org/10.1088/1757-899X/420/1/012059

Tambun R., Pakpahan Y., Christamore E. and Haryanto B. (2018b) Influence of Tannin Concentration from Banana Peel as Iron Inhibition in Hydrochloric Acid Solution, In Proceedings of the International Conference of Science, Technology, Engineering, Environmental and Ramification Researches (ICOSTEERR 2018) - Research in Industry 4.0, 297-301. https://doi.org/10.5220/0010087502970301

Tambun R., Christamore E., Pakpahan Y. F., Fitri M. W. D. et al. (2020) The utilization of banana peel as an organic corrosion inhibitor of zinc in chloride acid medium, *ARPN J. of Eng. and Applied Sci*., 15 (17),1854-1859.https://api.semanticscholar.Org/Corpus

Tiwari P., Srivastava M. Mishra R., Ji G. *et al.* (2018) Economic use of waste Musa paradisica peels for effective control of mild steel loss in aggressive acid solutions, *J. Environ. Chem. Eng*., 6(4), 4773–4783. https://doi.org/10.1016/j.jece.2018.07.016

Vasudha V. G. and Shanmuga P. K. (2013) Polyalthia Longifolia as a corrosion inhibitor for mild steel in HCl solution, *Res. J. Chem. Sci.*, 3(1), 21-26.

Verma D. K. and Khan F. (2016) Green Approach to Corrosion Inhibition of Mild Steel in Sulphuric Acid Solution using Extract of Banana Leaves, *Chem. and Mater. Res*., 8(5), 19-24.

Zhao B., W. Han, W. Zhang and Shi B. (2018) Corrosion inhibition performance of tannins for mild steel in hydrochloric acid solution, *Res. Chem. Intermed*., 44(1), 407-423. DOI:10.1007/s11164-017-3111-4

(2025); http://www.jmaterenvironsci.com